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Disk Drive With Read While Write Capability

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Field of the Invention

The present invention relates~~d~~ generally to disk drives and in particular to ~~read/write~~ preamplifiers for disk drives.

Background of the Invention

Data storage device~~system~~s such as disk drives are us~~tiliz~~ed for data storage and retrieval in a variety of applications. A ~~typical~~ disk drive includes a disk for storing information, a transducer (read/write) head for reading data from and writing data to the disk, a spindle motor for rotating the ~~a data~~ disk,~~, and an actuator for moving~~ a head carrier that supports the transducer head and an actuator for moving the head carrier and the transducer head ~~transducer (read/write) heads radially across the disk to write data to or read data from concentric data tracks on the disk~~. The disk drive may ~~Many disk drives~~ include multiple ~~a plurality of~~ disks separated by spacer rings and stacked on a hub attached to the spindle motor, multiple transducer ~~a plurality of read/write~~ heads~~,~~ and multiple ~~a plurality of~~ head carriers that ~~,~~ each ~~head carrier~~ support~~ing~~ at least one transducer ~~read/write~~ head. The disk includes concentric tracks that each include servo sectors and interleaved data sectors. To access a data sector~~segment starting on a track~~, ~~in a seek operation~~ the transducer head is moved radially across the tracks in a seek operation to the destination ~~the desired~~ track that contains ~~where~~ the data sector, and then~~gment starts.~~ ~~Thereafter,~~ the ~~rotation of the~~ disk rotates the data sector~~gment on the track~~ under the transducer head for ~~writing data to or~~ reading data from or writing data to the data sector~~refrom~~.

The disk drive further includes a preamplifier ~~electrically~~ connected to the transducer heads. T~~During operation of the disk drive, t~~he preamplifier provides two mutually exclusive ~~functional~~ data transfer modes: a read mode in which data recorded on the disk is sensed by the transducer head and transmitted to the preamplifier for amplification in a read operation, and a write mode in which ~~, wherein~~ data ~~is~~ transmitted to the preamplifier is ~~via a write data input and is subsequently~~ recorded on ~~to~~ the ~~data~~ disk by the transducer head in a write operation ~~via a head; and read mode, wherein magnetic signals sensed by a head subsequently undergo signal processing within the preamplifier before output from the preamplifier~~.

T~~Because the read and write functions are mutually exclusive, t~~he ~~conventional~~ disk drives has ~~suffer from~~ timing constraints which limit performance ~~the disk drives signal handling. These limitations directly effect several functions~~due to the read and write operations being mutually exclusive (not overlapping or simultaneous)~~ and processes common to most disk drive devices~~. For example, the ~~mutually exclusive preamplifier does not allow the~~ disk drive cannot ~~to:~~ (1) ~~perform~~ self-servo write~~ing~~ ~~with an absolute timing and position reference~~ by reading a reference pattern from one disk surface while writing ~~a~~ servo patterns to another disk surface, (2) reprocess (erase) a previously written ~~data~~ disk by reading from one disk surface while writing an erase pattern to another disk surface without ~~the need for~~ an external positioning device or a time consuming algorithm~~s, by reading on one head while writing an erase pattern on one more heads at the same time~~, (3) ~~perform efficient tests for high density data disks to~~ reduce test time by reading from one disk surface while writing to another disk surface~~data~~, (4) increase read accuracy by reading head position information from one disk surface while writing to another disk surface, or (5~~4~~) increase ~~data~~ write accuracy by reading from one disk surface ~~effectively adjusting for head positioning errors due to disk flapping modes that cause unwanted disturbances~~while writing to another disk surface~~, (5) increase data read accuracy and efficiency by reading head position information and track centering on one head while writing with another head on another surface, etc~~.

~~In servo writing, servo patterns are typically written with uniform angular spacing of servo sectors and interleaved data sectors or blocks. An example servo pattern includes~~

~~circumferentially sequential, radially staggered single or multiple frequency bursts.~~ The s~~S~~ervo patterns in the servo sectors provide ~~the disk drive with~~ head position information to enable the actuator~~, such as a rotary voice coil positioner,~~ to move the transducer head from the starting track~~s~~ to the destination track~~s~~ during a ~~random access track~~ seek~~ing~~ (track-to-track) operation~~s~~, and to ~~. Further, the servo patterns provide the disk drive with head position information to enable the actuator to position and~~ maintain the transducer head in proper alignment with the~~a~~ track centerline of the destination track while data is read from or written to the destination track during a track~~-~~following (on-track) operation~~s when user data is written to or read from the available data block storage areas in concentric data tracks on the disk surface~~. The servo patterns typically have uniform angular spacing and include circumferentially sequential, radially staggered single or multiple frequency bursts.

The ~~Conventionally~~ servo patterns can be ~~are~~ written ~~into the servo sectors of each disk~~ using a servo writer ~~at a point in the drive assembly process before the hard disk unit is sealed against particulate contamination from the ambient.~~. The ~~A~~ servo writer is a complex and expensive machine ~~manufacturing unit,~~ typically stabilized on a large granite base to minimize unwanted vibration and employs~~ing e.g.~~ laser interferometry for precise position measurements._ The servo writer typically requires direct mechanical access to the head carrier~~arm,~~ and includes a fixed head for writing a clock track ont~~o~~ a- disk surface._ The servo writer writes the servo patterns before the disk drive is sealed against particulate contamination.

~~Because of the need for direct access to the interior of the hard disk assembly of each disk drive unit,~~ T~~t~~he servo writer is typically located within a clean room where the air is purged of impurities that might otherwise interfere with ~~operation including~~ the servo writing ~~process~~ or ~~in~~ normal disk drive operation ~~usage~~ after manufacturing.—_Further, ~~such conventional~~ servo_-writing by the servo writer is ~~methods are~~ very time consuming. _In one example, a disk drive having two disks with four disk~~data storage~~ surfaces can require three servo_-writer_-controlled passes of the transducer head over a single track ~~during servo writing~~, consuming a total servo writing time as long as 18.2 minutes. S~~Thus, s~~ervo writing using servo writers in clean rooms requires both considerable capital investment ~~in the manufacturing process~~ and severe time penalties ~~in the manufacturing process~~ attributable to servo writer bottlenecks. Further, as track densities increase with evolving ~~hard~~ disk drive

designs, servo writers ~~become obsolete, and~~ have to be replaced~~,~~ or upgraded~~,~~ at considerable capital expense.

The servo patterns can also be written using self-servo writing. A reference pattern ~~To solve the above problems, another conventional method is directed to servo writing a master pattern~~ at full resolution is magnetically printed on a~~one~~ disk surface of a reference ~~master~~ disk ~~during~~ by a magnetic printing station during a pre-assembly operation. Then~~,~~ reference ~~a master~~ disk with the reference ~~master~~ pattern is then assembled with ~~other~~ blank disks into the ~~a~~ disk drive ~~unit~~. After the disk drive ~~unit~~ is sealed ~~against the ambient~~, the disk drive uses the reference ~~master servo~~ pattern to ~~of the master disk is used as a reference by the disk unit in~~ self-servo write~~ing~~ embedded ~~sector~~ servo patterns on each disk ~~data~~ surface within the disk drive~~enclosed unit~~. Thereafter, ~~Finally,~~ the reference~~master~~ pattern is erased, leaving the disk drive ~~unit~~ with properly located ~~embedded~~ servo ~~sector~~ patterns on every disk surface, including the disk surface which ~~originally~~ included the reference~~master~~ pattern. However, ~~such a method had several~~ disadvantages of this approach include~~:~~ (1) the self-servo-write~~ing~~ ~~time~~ is ~~very~~ time consuming~~long~~, (2) ~~certain~~ repeatable run-out ~~information~~ must be removed during the self-servo write~~operation~~,~~;~~ (3) the magnetic printing station is ~~a number of~~ expensive, ~~servo writers are still required to write the master patterns on the master disks;~~ and (4) the reference disk has ~~and~~ no absolute reference and ~~from the reference disk is available during servo writes to a blank disk~~ since read and write operations are mutually exclusive, ~~and possible~~ defects in the reference disk~~printed media~~ can exacerbate the problem~~, etc.~~.

There is, therefore, a need for a data storage device, such as a disk drive, with simultaneous read and write capability. There is also a need for ~~a~~ self-servo write ~~method~~ with ~~utilizing~~ simultaneous read and write operations ~~to alleviate the above problems, and provide a means~~ to cost effectively enhance data storage device manufacturing and performance.

~~Brief~~ Summary of the Invention

The present invention ~~alleviates the aforementioned shortcomings. In one embodiment, the present invention~~ provides a data transfer driver ~~comprising a preamplifier~~ for a data storage device. The data transfer driver includes a preamplifier, and the data

storage device~~disk drive~~ includes~~ing~~ a recording media having one or more recording surfaces, and one or more ~~data~~ transducer heads positionable relative to the recording surfaces by a~~ head position~~n actuator ~~structure~~ operating within a head position servo loop. The preamplifier includes ~~comprises: a control interface for receiving preamplifier configuration information to selectively transfer data to and from recording surfaces;~~ one or more head interfaces, each head interface ~~electrically~~ connected to a transducer head for controlling the transducer head for data read and/or write operations, ~~;~~ and a mode controller ~~electrically~~ connected to ~~the control interface and to~~ each head interface~~,~~ for controlling the operation of each head interface ~~based on the configuration information~~ for selectively reading from at least one recording surface via at least one transducer head while writing ~~data~~ to at least one recording surface via at least one transducer head.

The preamplifier receives configuration information to selectively transfer data to and from recording surfaces such that the mode controller controls the operation of each head interface based on the configuration information.

The configuration information includes (1) a read mode in which the mode controller controls the operation of the head interfaces for selectively reading data via at least one transducer head, (2) a write mode in which the mode controller controls the operation of the head interfaces for selectively writing data via at least one transducer head, (3) a servo write mode in which the mode controller controls the operation of the head interfaces for selectively writing data via multiple transducer heads, and (4) a read-while-write (RWW) mode in which the mode controller controls the operation of the head interfaces for selectively reading data from at least one recording surface via at least one transducer head while writing data to at least one recording surface via at least one transducer head.

The configuration information can be set, for instance, to the RWW mode for selectively reading data from at least one recording surface via at least one transducer head while simultaneously writing data to multiple recording surfaces via multiple transducer heads.

The configuration information can also be set, for instance, to the servo write mode and the RWW mode for selectively reading data from at least one recording surface via at

least one transducer head while writing servo patterns to at least one recording surface via at least one transducer head.

T~~Further, the preamplifier can be used for separately writing data to at least one recording surface and/or reading data from at least one recording surface.~~

~~In another aspect, t~~he present invention also provides disk drive ~~a method for~~ self-servo writing ~~a disk drive~~ by ~~first~~ transferring a ~~servo~~ reference pattern to a ~~recording surface of a~~ reference disk. T~~, wherein t~~he reference pattern includes (1) a ~~comprises~~ servo clock that provides ~~information providing~~ transducer head circumferential relative position information,~~;~~ and (2) servo position information that provides ~~providing~~ transducer head radial relative position information. The~~reafter, the disk drive is assembled by installing the~~ reference disk and one or more data disks are installed into ~~into the disk drive and enclosing~~ the ~~disks and data transducers within a~~ disk drive~~housing~~. Then, during ~~For~~ self-servo write~~ing,~~ , the reference pattern is read from the reference disk via a transducer head~~,~~ and ~~using~~ the read servo clock and the servo position information are used to position and maintain ~~-~~one or more transducer heads ~~are positioned and maintained~~ at concentric track~~ locations~~ on~~of~~ one or more ~~data disk~~ recording surfaces to simultaneously write ~~disk drive~~ servo patterns ont~~o~~ the recording surfaces. Advantageously, rather than

~~Conventionally,~~ reading the ~~a~~ reference pattern from the reference disk ~~from the disk surface~~ via a transducer ~~read~~ head ~~is~~ sequentially followed by switching to other transducer heads to write the servo ~~a servo~~ patterns on the data disks, as is conventional~~wherein the read and write operations are mutually exclusive~~, the reference pattern is read via one transducer head to simultaneously clock out the servo patterns via the other transducer heads~~ (i.e., not overlapping or simultaneous~~). Therefore, ~~he conventional self-servo write process switches between reading and writing until the entire servo pattern is written out on a disk. However, according to the present invention~~ there is no need to switch-out ~~of~~ the reference pattern to write the servo patterns~~ on data disks. The reference information (e.g., timing and position information) obtained from the reference disk via one head is used to simultaneously clock out servo patterns to other data disks on other heads.~~

Brief Description of the Drawings

These and other features, aspects and advantages of the present invention will become understood with reference to the following description, appended claims and accompanying figures where:

FIG. 1 shows a ~~block diagram of the architecture of an embodiment of a~~ computer system that includes a disk drive~~including a disk storage system according to an aspect of the present invention~~;

FIG. 2~~2~~ shows a drive controller of the disk drive~~n example block diagram of the architecture of an embodiment of the drive electronics of disk drive of FIG. 1 according to the present invention~~;

FIG. 3 shows a head disk assembly of the disk drive;

FIGS. 4A-4B~~3~~ show~~s~~ the drive controller and the head disk assembly in ~~a~~ more detail~~ed block diagram of the drive electronics of FIG. 2~~;

FIGS. 5A-5B~~4~~ show~~s~~ a~~n example block diagram of an embodiment of a~~ preamplifier of the head disk assembly~~circuit of FIG. 3 showing example read head and write head selection circuitry according to the present invention~~;

~~FIG. 5 shows an example block diagram of another embodiment of the preamplifier circuit of FIG. 3 showing example read head and write head selection circuitry according to the present invention;~~

FIG. 6 shows a ~~highly diagrammatic representation of an embodiment of a~~ magnetic printing station that prints a reference pattern on a reference disk~~for printing a reference disk storage surface with a servo reference pattern~~;

FIG. 7 shows the reference pattern;

FIG. 8 shows the reference pattern in more detail;

FIG. 9~~7~~ shows the disk drive with the reference pattern in a self-scan station before self-servo write~~a diagrammatic representation of an embodiment of a disk drive including a disk with a servo reference pattern according to the present invention; and~~

FIG. 10~~8~~ shows ~~an example functional diagram of~~ the disk drive performing self-servo write~~ing according to an aspect of the present invention~~;

FIG. 11 shows a head position servo loop of the disk drive;

FIG. 12 shows the disk drive generating servo patterns for self-servo write;

FIG. 13 shows a flow diagram for self-servo write;

FIGS. 14~~9~~A-14B show~~s~~ a~~n example~~ flow chart for~~iagram of~~ self-servo write~~ing according to the present invention;~~

~~FIG. 10A shows an example reference pattern according to the present invention;~~

~~FIG. 10B shows an example flow diagram of head position control while self-servo writing using the reference pattern of FIG. 10A;~~

~~FIG. 10C shows a details of a portion of the reference pattern of FIG. 10A;~~

~~FIG. 11 shows an example diagram for generating a final servo patterns according to the present invention;~~

~~FIG. 12 shows an example flow diagram for writing final servo patterns according to the present invention~~; and

FIG. 15~~3~~ shows a~~n example~~ flow diagram for~~of~~ self-reprocessing faulty servo patterns~~according to the present invention~~.

To facilitate understanding, identical reference numerals have been used, at times with suffixes A, B, and so on~~where possible~~, to designate structurally/functionally identical or similar elements that are common throughout the figures.

Description of the Invention

~~Referring to~~ FIG. 1 shows a ~~, an example~~ computer system 10 that ~~is shown to include a disk storage unit according to the present invention. The computer system 10~~ includes a central processing unit ("CPU") 12~~4~~, a main memory 14~~6~~, an~~d~~ I/O bus adapter 16, ~~8, all interconnected by~~ a system bus 18~~20~~, ~~. Coupled to the I/O bus adapter 18 is~~ an I/O bus 20~~2~~, a peripheral device 22 and a disk drive 24. The CPU 12, the main memory 14 and the I/O bus adapter 16 are connected by the system bus 18, and the I/O bus adapter 16 is connected to the peripheral device 22 and the disk drive 24 by the I/O bus 20 (such as ~~that can comprise e.g.~~ a ~~small computer system interconnect~~ ~~(~~SCSI~~)~~ bus). ~~, and which supports various peripheral devices 24 including a disk storage unit such as a disk drive 25.~~ The disk drive 24~~5~~ includes a drive controller ~~controller electronics~~ 26 and a head disk assembly ~~28~~ ("HDA") 28.

~~As shown in FIG . 7, in one embodiment, the HDA 28 includes data disks 29 rotated by a spindle motor 23, and transducer heads 27 moved radially across the data disks 29 by one or more actuators 37 for writing data to and reading data from the data disks 29.~~

~~Referring to~~ FIGS. 2~~2-3~~ shows ~~, in one embodiment,~~ the drive controller 26 in more

detail. The drive controller 26 ~~electronics 26 of FIG. 1~~ includes a data controller 30, a servo controller 32, a read/write channel 34, a bus 36 and a data buffer bus 38. The data controller 30 is ~~-inter~~connected to the~~a~~ servo controller 32~~34~~ by the ~~via a~~ bus 36~~31~~, and the data controller 30 is ~~a read/write channel 32 inter~~connected to the channel 34 by the ~~data controller 30 via a~~ data buffer bus 38~~33~~. The data controller 30 is also connected to the I/O bus 20, and the servo controller 32 and the channel 34 are ~~The read/write channel 32 and the servo controller are~~ connected to ~~a read~~ the HDA 28~~, and specifically, in one version, to a data transfer driver comprising a preamplifier/head-select/write driver circuit 11 (preamplifier/circuit 11) in the HDA 28~~. The drive controller 26 also includes a printed circuit board (not shown) that carries large scale integrated circuits and other components.

FIG. 3 shows the HDA 28 in more detail. The HDA 28 includes the disks 40, the transducer heads 42, the carrier arms 44, the hub 46, the spindle motor 48 and the actuator 50. The disks 40 are mounted on the hub 46 and rotated by the spindle motor 48. The transducer heads 42 are supported by the carrier arms 44 and moved radially across the disks 40 by the actuator 50 (such as a voice coil motor). The disks 40 include the disk surfaces 52, and the transducer heads 42 read from and write to the corresponding disk surfaces 52.

During a typical read operation, the CPU 12 requests data from the disk drive 24, and the data is transferred ~~One function of the preamplifier/write driver 11 is to preamplify the electrical signals transduced from the recorded flux transitions on the surfaces 98 of the disks 29 during reading via heads 27, and to amplify the driving current for writing data to the surfaces 98 of the disks 29 during data writing operations via heads 27. Further, the circuit 11 selects the transducer head(s) 27 for read/writing data as described further below.~~

~~A typical data write operation initiated by the CPU 14 (FIG. 1) to the disk drive 25 may involve, for example, a direct memory access ("DMA") transfer of digital data from the memory 16 onto the system bus 20. Data from the system bus 20 is transferred by the I/O adapter 18 onto the I/O bus 22. The data is read from the I/O bus 22 by the data controller 30, which formats the data into data segments with the appropriate header information and transfers the data to the read/write channel 32. The read/write channel 32 operates in a conventional manner to convert data between the digital form used by the data controller 30~~

~~and the analog form suitable for writing to data disks by transducers 27 in the HDA 28 selected by the preamplifier circuit 11.~~

~~For a typical read request to transfer data segments~~ from the disk 40~~HDA 28~~ to the CPU 124. T~~, t~~he data controller 30 provides a ~~disk~~ track ~~location~~ where the data is stored to the servo controller 324 ~~where the requested data segments are stored~~. T ~~In a seek operation, t~~he servo controller 324 provides control signals to the HDA 28 to ~~for~~ command~~ing~~ the~~an~~ actuator 50~~37~~ to position the~~a~~ transducer head 42 ~~27~~ over the track where the data is stored in a seek operation~~said disk track for reading the requested data segments therefrom~~. The transducer head 42 reads the data from the disk 40 and generates an analog read signal~~Data read from the transducer 27 is preamplified in the preamplifier 11~~, ~~and~~ the ~~read/write~~ channel 34~~2~~ converts the read signal ~~analog data signals from the preamplifier 11~~ into digital data, the data controller 30 transfers the data to ~~and transfers the data to the data controller 30. The data controller 30 places the digital data on~~ the I/O bus 20~~2~~, and ~~wherein~~ the I/O bus adapter 16~~8~~ route~~reads the data from the I/O bus 22 and transfers~~ the data from the I/O bus 20 to the main memory 14~~6~~ via the system bus 18~~20~~ for access by the CPU 124.

The transducer head 42 also reads servo patterns from the disk 40 and generates an analog read signal, the channel 34 converts the read signal into head position information, and the servo controller 32 ~~In one example, the surfaces 98 of data disks 29 include head positioning servo patterns, wherein for servo operations, head positioning information from data disks 29 are induced into the transducers 27, converted from analog signals to digital data in the read/write channel 32, and transferred to the servo controller 34, wherein the servo controller 34 utilizes~~ uses the head positioning information for ~~for performing~~ seek and track-following ~~ing~~ operations~~of the transducers 27 over tracks on disks 29. In another example described further below (FIG. 7), the disks 29 do not include servo patterns, and the disk drive 25 includes a reference disk 76 having reference patterns thereon which are utilized in a self-servo writing process according to an aspect of the present invention to write servo patterns on the disks 29~~.

During a typical write operation, the CPU 12 requests that data be stored in the disk drive 24, and the data is transferred from the CPU 12 to the disk 40. For example, with

direct memory access (DMA), the I/O bus adapter 16 routes the data from the main memory 14 to the data controller 30 via the buses 18 and 20. The data controller 30 formats the data into blocks with appropriate headers, the channel 34 converts the data into analog form suitable for writing, and the transducer head 42 writes the data to the disk 40.

FIGS. 4A-4B show the drive controller 26 and the HDA 28 in more detail.

The drive controller 26 includes a power circuit 54. The servo controller 32 includes a multiplexer 56, a pattern generator 58, a clock multiplier (state machine) and phase locked loop (PLL) 60, a read only memory (ROM) 62, the registers 64, a servo processor 66, a servo control interface 68, a read/write interface 70 and a serial interface 72. The channel 34 includes an automatic gain control (AGC)/filter 74, a pulse detector 76, a partial response maximum likelihood (PRML) circuit 78, a servo demodulator and analog-to-digital converter (ADC) 80 and a signal controller 82. The power circuit 54 includes a digital-to-analog converter (DAC) 84 and a driver 86.

The HDA 28 includes a preamplifier 88 that amplifies the read signal sent from the transducer heads 42 during a read operation and amplifies the write current sent to the transducer heads 42 during a write operation. The preamplifier 88 also selects the transducer heads 42 for the read and write operations based on configuration information sent from the drive controller 26. The configuration information includes head selection and data transfer mode information that selectively configures the preamplifier 88 for independent control of the transducer heads 42.

The p~~FIG. 3 shows an example block diagram of an embodiment of the circuit 11. In this embod~~reamplifier 88~~iment, the circuit 11~~ includes a~~t least one~~ mode controller 90 that receives and maintains the configuration information. The mode controller 90 includes an ~~control~~ interface ~~interface~~ register 92, a read select register 94, a write select register 96 and a mode register 98. The registers 92, 94 and 96 are serial registers. The mode controller 90 receives the configuration information as an external state signal such as a serial word ~~comprising e.g. registers 36 for receiving and maintaining information (e.g., configuration information) transmitted to the circuit 11~~ from ~~an external source such as~~ the data controller 30, the servo controller 32 and/or the channel 34~~2 and/or the servo controller 34~~. ~~The~~

~~configuration information is used to selectively configure the operation of the circuit 11, including head selection and data transfer operation modes (e.g., via mode control bits) described below. In one example, the configuration information includes mode select information such as e.g. data transfer and head select control signals.~~

The preamplifier 88 also ~~example circuit 11 further~~ includes a read multiplexer 100 and a write multiplexer 102. The read multiplexer 100 includes ~~head interfaces comprising at least~~ the~~a~~ read circuits 104, and the write multiplexer 102 includes the ~~38 and at least a~~ write circuits 106~~40~~. The read circuits 104 each include a tri-state differential receiver and buffer, and the write circuits 106 each include a tri-state differential driver and buffer. The read circuits 104 and the write circuits 106 can also provide additional signal processing. The read circuits 104 and the write circuits 106 are arranged in pairs such that one read circuit 104 and one write circuit 106 are connected to a single transducer head 42. In this manner, each read circuit 104 and write circuit 106 pair provides a head interface 108 that controls a corresponding transducer head 42 for read and/or write operations. Alternatively, the read multiplexer 100 can include one read circuit 104 that is connected to a selected one of the transducer heads 42 by a multiplexer, and the write multiplexer 102 can include one write circuit 106 that is ~~, wherein in one embodiment of the circuit 11 the read circuit 38 can be~~ connected to a selected one of the transducer ~~multiple~~ heads 42~~27~~ by a multiplexer~~ function, and similarly the write circuit 40 can be connected to a selected one of multiple heads 27 by a multiplexer function. In other example versions of the circuit 11 shown in FIGS. 4-5, and described below, the circuit 11 includes a read circuit 38 and a write circuit 40 for each transducer head 27, to write data and read data, respectively~~r.

~~The circuit 11 further includes a mode control 41 (e.g., register or multiplexer) to provide control signals to the read and write circuits 38, 40 based on data transfer mode select information provided by the controller 34 to the register 36 of the circuit 11 for selecting one or more heads 27 for read/write operations via the read and write circuits 38, 40, respectively. Further, the mode controller 41 emits control signals to e.g. read and write cricuits 38, 40 and heads 27 to ascertain their individual operating modes at any given time.~~

The transducer heads 42 each include an MR reader 110 and a writer 112.

The interface register 92 input is connected to the clock/data line 114, and the mode controller 90 input is connected to the read/write (R/W) select line 116. The read multiplexer 100 head select input is connected to the read select register 94 by the read head select line 118, and the read multiplexer 100 enable input is connected to the mode register 98 by the read enable line 120. Likewise, the write multiplexer 102 head select input is connected to the write select register 96 by the write head select line 122, and the write multiplexer 102 enable input is connected to the mode register 98 by the write enable line 124. ~~In one example embodiment, each read circuit 38 comprises a tri-state differential receiver and buffer, and each write circuit 40 comprises a tri-state differential driver and buffer.~~ The reader circuit 104 input is connected to the corresponding MR reader 110 by the read data lines 126, and the reader circuit 104 output is connected to the differential read data lines 128 which are inverted with respect to each other to improve noise immunity. Likewise, the writer circuit 106 input is connected to the differential write data lines 130 which are inverted with respect to each other to improve noise immunity, and the writer circuit 106 output is connected to the corresponding writer 112 by the write data lines 132. ~~Data to be written is provided to each write circuit 40 along data lines 42. Preferably, a pair of lines 42 provide data to each write circuit 40, wherein both lines 42 carry the same signal, but each line 42 is inverted with regard to the other to provide noise immunity. In one version, each head 27 includes a reader element and a writer element, each writer element connected to output of a respective write circuit 40 via lines/nodes 44. Similarly, for each read circuit 38, a pair of read data lines 46 provide data signal read from the heads 27, wherein each line 46 is inverted with respect to the other line 46 to provide noise immunity. The input of each read circuit 38 is connected to a reader element of a respective head 27 via lines/nodes 48.~~

The drive controller 26 sends the configuration information to the mode controller 90 using the clock/data line 114 and/or the R/W select line 116. The lines 114 and 116 are serial lines, and the R/W select line 116 toggles a R/W signal between read (high) and write (low). The configuration information received by the mode controller 90 sets selection bits in the read select register 94 and the write select register 96 to designate the selected read circuits 104 and write circuits 106, respectively. The mode register 98 accesses the read select register 94 and the write select register 96 to selectively enable and disable the read circuits 104 and the write circuits 106 based on the configuration information.

The mode controller 90 selects one or more of the transducer heads 42 for read/write operations via the head interfaces 108 based on the configuration information. The mode controller 90 also ascertains the individual operating modes of the transducer heads 42, the read circuits 104 and the write circuits 106 at any given time.

~~The data read by a head 27 passes through the preamplifier circuit 11 which also provides head selection and write driving functions during data write operations. As shown in the example~~ FIGS. 5A-5B show~~4,~~ the preamplifier 88 in more detail. The preamplifier 88 includes the head interfaces 108A, 108B, 108C and 108D. The head interfaces 108A, 108B, 108C and 108D are connected to and control the read/write operations of the transducer heads 42A, 42B, 42C and 42D, respectively. The head interface 108A includes the read circuit 104A and the write circuit 106A, the head interface 108B includes the read circuit 104B and the write circuit 106B, the head interface 108C includes the read circuit 104C and the write circuit 106C, and the head interface 108D includes the read circuit 104D and the write circuit 106D. For convenience of illustration, more head interfaces 108 are not shown.

The mode controller 90 in this embodiment implements the multiplexer functions of the read multiplexer 100 and the write multiplexer 102 to provide separate controls lines for each read circuit 104 and write circuit 106. The mode controller 90 enables and disables the read circuits 104A, 104B, 104C and 104D using the read control lines 134A, 134B, 134C and 134D, respectively, and enables and disables the write circuits 106A, 106B, 106C and 106D using the write control lines 136A, 136B, 136C and 136D, respectively. As a result, the transducer heads 42A, 42B, 42C and 42D are individually controlled for read and/or write operations.

The configuration information includes ~~circuit 11 enables four separate heads 27 to be individually selected. Based on the information in the registers 36, the mode control 41 enables the circuit 11 to provide~~ several functional/operational modes~~including~~: (1) a read~~Write~~ m~~M~~ode, (2) a write~~Read~~ m~~M~~ode, (3) a s~~S~~ervo write mode, ~~Mode~~ and (4) a r~~R~~ead-w~~-W~~hile-w~~-W~~rite~~, or simultaneous read and write,~~ ("RWW") mode~~. In one example, the mode control 41 comprises a multiplexer wherein at least the registers 36 provide selection signals to the multiplexer 41, whereby the multiplexer 41 generates control output signals for~~

~~selecting/enabling the read and write circuits 38, 40 of the circuit 11, and transducer heads 27, according to the present invention~~.

~~In the Write Mode, the circuit 11 provides functions including receiving data transmitted to write data inputs 50 of the circuit 11 by e.g. the read/write channel 32 (or the controller 34) and recording the received data to a surface 98 of a disk 29 using at least one selected write circuit 40 and a corresponding head 27 in a write operation.~~

-In the r~~R~~ead m~~M~~ode, the mode controller 90 controls the head interfaces 108 for selectively reading data from at least one of the disk surfaces 52 via at least one of the corresponding transducer heads 42. ~~circuit 11 provides functions including receiving signals sensed by at least one selected head 27 via a read circuit 38, at read data outputs 52 of the circuit 11.~~ In a typical read~~/write~~ operation, the mode controller 90 selects one~~a single~~ transducer head 42~~27~~ ~~is selected~~ for reading from the corresponding disk surface 52. Accordingly, the mode controller 90 enables the read circuit 104 for the selected transducer head 42, disables the write circuit 106 for the selected transducer head 42 and disables the read circuits 104 and the write circuits 106 for the other transducer heads 42~~by the mode control 41 according to head selection information received by the registers 36 (e.g., serial interface (SIF) registers) from the read/write channel 32 (or the controller 34). In one example, the circuit 11 utilizes an external state signal (e.g., serial word) from the read/write channel 32, providing the state of each head on an external pin 54 (R/-W), wherein the head state information includes whether a selected head 27 is in read or write mode (e.g., R/-W hi indicates read mode, whereas R/-W low indicates write mode). The mode control 41 in circuit 11 utilizes the head state information to change the state of a selected head 27 as necessary based on the required read/write operation~~.

In the write mode, the mode controller 90 controls the head interfaces 108 for selectively writing data from at least one of the transducer heads 42 to at least one of the corresponding disk surfaces 52. In a typical write operation, the mode controller 90 selects one transducer head 42 for writing to the corresponding disk surface 52. Accordingly, the mode controller 90 enables the write circuit 106 for the selected transducer head 42, disables the read circuit 104 for the selected transducer head 42 and disables the read circuits 104 and the write circuits 106 for the other transducer heads 42.

In the s~~S~~ervo write m~~M~~ode, the mode controller 90 controls the head interfaces 108 for selectively writing servo patterns from at least one of the transducer heads 42 to at least one of the corresponding disk surfaces 52. For example~~circuit 11 provides functions including receiving data transmitted to the write data inputs 50, and recording the received data to one or more surfaces 98 using one or more selected write circuits 40 and one or more corresponding heads 27 in a write operation. In one version~~, the mode controller 90 selects multiple transducer heads 42 for writing servo patterns to the corresponding disk surfaces 52 ~~servowrite mode is accomplished by the mode control 41 enabling the writer element of multiple heads 27 simultaneously, wherein the same input data from the write data inputs 50 are sent to multiple heads 27 for writing~~ simultaneously ~~at the same time~~ or in overlapping form but does not select any transducer head 42 for reading since the ~~. In this case, reader elements of multiple heads 27 are not enabled at the same time because~~ read and write operation~~function~~s are gated by the ~~state of~~ R/-W signal and therefore are ~~, and the read and write functions can only be~~ mutually exclusive.

In the r~~R~~ead-w~~W~~hile-w~~W~~rite (RWW) mode, the mode controller 90 controls the head interfaces 108 for ~~circuit 11 provides functions including~~ simultaneously~~:~~ (1) selectively reading data from at least one of the disk surfaces 52 via at least one of the corresponding transducer heads 42, and (2) selectively writing data from at least one of the transducer heads 42 to at least one of the corresponding disk surfaces 52~~receiving signals sensed by at least one selected head 27 at read inputs of a corresponding read circuit 38, processing the signal within the read circuit 38, and outputting the read data at the read data outputs 52 of the circuit 11, and (2) receiving data transmitted to write data inputs 50 of the circuit 11, processing the write data signals within one or more selected write circuits 40, and recording data output from the selected write circuits 40 to a surfaces 98 of one or more disks 29 using one or more corresponding heads 27 in a write operation.~~ For

~~In one RWW~~ example, the mode controller 90 selects one transducer head 42 for reading and writing. As another example, the mode controller 90 selects one transducer head 42 for reading and another transducer head 42 for writing~~at least one head 27 and corresponding read circuit 38 are selected for a read operation, and at least another head 27 and corresponding write circuit 40 are selected for a write operation.~~ ~~In another RWW~~

~~example, the same head 27 and corresponding read and write circuits 38, 40 are selected for simultaneous read and write operations using that one selected head 27.~~ As another example, ~~Other examples are possible, such as,~~ the mode controller 90~~41~~ ~~can~~ selects one transducer head 42 for reading and other transducer heads 42 for writing~~a single read circuit 38 to supply output signals read from a disk surface 98 by a corresponding head 27 to the read data outputs 52, while simultaneously selecting one or more write circuits 40 for writing data to one or more disk surfaces 98 via corresponding heads 27. As such, the circuit 11 outputs a signal read by a head 27 via a corresponding read circuit 38, while servowrite mode is in effect (e.g., servowrite mode enabled and R/-W is low), wherein data is written via one or more selected write circuits 40 and corresponding heads 27. Each of the circuits 38, 40 can include additional components for further processing of read/write signals.~~

The servo write mode and the RWW mode can be used together. For ~~In one embodiment, the mode control 41 comprises a multiplexer circuit (Mode Control Mux) providing control signals via control lines 56, 58 to the read and write circuits 38, 40, respectively, based on the information in the registers 36. The circuit 11 includes a control line 56 for each read circuit 38, and a control line 58 for each write circuit 58. The model control 41 controls (e.g., enable/disable) the read and write circuits 38, 40. In one RWW scenario, to read data, the mode control 41 enables a selected read circuit 38 and corresponding head 27, and disables the remaining read circuits 38 in the circuit 11 to prevent simultaneous transfer of data from more than read circuit 38 to the read data outputs 52 of the circuit 11.~~

~~Utilizing enable/disable is an example form of write control and read control. Write control and read control can be used in combination with enable and disable controls. A control register controls the head read bias to control read. As such, the control of the reader portion of a head 27 for RWW can be controlled by e.g. one or more of the following: Bias Enable (Controller flips the bit); Reader Mux select/deselect; Read driver 38 enable/disable.~~

~~To write data, the mode control 41 enables one or more selected write circuits 40 and corresponding heads 27 for writing data. For example, the circuit 11 provides Servowrite Mode by enabling a plurality of selected write circuits 40 and corresponding heads 27~~

~~simultaneously, wherein the same data from the write data inputs 50 of the circuit 11 is provided to each enabled write circuit 40 for recording a plurality of disk surfaces 98 by a plurality of corresponding heads 27.~~

~~In one implementation, the registers 36 comprise a read head select register 60, a control register 62, and a write head select register 64. The circuit 11 provides independent control of read and write circuits 38, 40 and corresponding heads 27 using the serial encoded control register 62. Based on the information in the control register 62, the mode control 41 enables or disables different task related modes (data transfer modes) where reading and writing combinations are different (e.g., Read Mode, Write Mode, Servowrite Mode, RWW Mode, etc). In one example, data transfer mode select information is provided by the controller 34 to the control register 62 of the circuit 11 for selecting one or more heads 27 for read/write operations via the read and write circuits 38, 40, respectively.~~

~~The head select registers 60, 64 store information for the mode control 41 to select one or more heads 27 for read and/or write operations, respectively. The control register 62 is used in conjunction with read and write head select registers 60, 64, whereby through coordination of aforementioned modes, and read/write circuit and head selections, the circuit 11 provides the disk drive 25 with the capability to perform functions not previously possible or cost-efficient. Such functions include self-servowriting, self-reprocessing, negating disk flapping when writing data fields, track-centering while writing (for dual actuator), calculating position error before head switches (single actuator), etc..~~

~~Referring to FIG. 5, in one RWW mode~~ example, the configuration information is pre-programmed and stored in the ROM 62. The servo processor 66 sends the configuration information from the ROM 62 to the interface register 92 via the serial interface 72 and the clock/data line 114. Alternatively, the servo processor 66 sends the head selection information to the interface register 92 via the serial interface 70 and the clock/data line 114, and the servo processor 66 sends the data transfer mode information to the mode controller 90 via the read/write interface 70, the signal controller 82 and the R/W select line 116~~a control bit in the~~. The configuration information sets a control bit in the interface register 92 ~~control register 62 signals the mode control 41~~ to place the mode controller 90 ~~circuit 11~~ in the s~~S~~ervo write m~~M~~ode. The configuration information also ~~Another~~ sets one~~of~~ bits in

the~~the control register 62~~ read select register 94 to select one transducer head 42 for reading and two bits in ~~act as an adjunct head select register, wherein based on~~ the write ~~head~~ select register 966 to 4~~, the mode control 41~~ selects two ~~a pair of~~ transducer heads 42~~27~~ for writing. The mode register 98 then commands the read selected transducer head 42 to read and the write selected transducer heads 42 to write, and the read and write operations are performed simultaneously ~~in Write Mode, leaving the read head select register 60 to select a head 27 to simultaneously read in Read Mode. For example, a processor 110 in the servo controller 34 (FIG. 3) provides mode select information to the mode control 41. In one case, pre-programmed mode information is stored in the memory 305 which is utilized by the processor 110 to specify selection of particular read and write circuits 38, 40. The mode information is communicated from the processor 110 via a serial data interface 303 in the controller 34, to the serial control register 62 and written to the read and write head select registers 60 and 64. Based on the mode information, the mode control 41 provides control signals 56, 58 to the read and write circuits 38, 40, respectively, to allow e.g. a single selected read circuit 38 to read data via a head 27 and supply an output signal to the read data output 52 of the circuit 11, while simultaneously selecting one or more write circuits 40 to write data from input 50 via one or more corresponding heads 27. In one example, the controller 41 further utilizes the state of the heads 27 for head selection (i.e. R/-W signal) described above.~~

~~As such in Servowrite Mode (i.e. servowrite mode enabled and R/-W is low), the circuit 11 processes an output signal from a read circuit 38. Further, an additional control bit in the mode control 41 prevents the read data path 46 from being disabled during the Servowrite Mode write operation (i.e. R/-W low) thus e.g. allowing reading of servo information while writing data, to be used in the normal drive operation for radial and circumferential positioning of the heads.~~

~~In another scenario, the circuit 11 performs the RWW function for the Read Mode and the Write Mode (in addition to that in the Servowrite Mode), wherein the control 41 provides control signals to the read and write circuits 38, 40 to read and write to the same head 27 simultaneously. Further, the circuit 11 can provide control signals to the read and write circuits 38, 40 for simultaneously: (1) receiving signals sensed by a plurality of selected heads 27 at inputs corresponding to selected read circuits 38, and transmitting the read data~~

~~at the read data outputs 52 of the circuit 11, and (2) receiving data transmitted to write data inputs of a plurality of the circuits 40 for recording to a plurality of surfaces 98 using a plurality of corresponding selected heads 27 in a write operation. In one version, at least one head 27 is selected for a read operation, and at least another head 27 is selected for a write operation simultaneously. In another version, the same head 27 is selected for simultaneous read and write operations.~~

~~The read channel circuitry can be modified to be independently selectable to be active or inactive during the write function, providing: (1) independent operation of the write and read paths through the read channel device, (2) support for simultaneous read and write data streams from the disk controller portion of the ASIC, and (3) redefined ASIC-Read channel interface.~~

~~The circuit 11 can be utilized in place of conventional read/write preamplifiers in many mass storage devices such as, but not limited to, hard disk drives. The RWW function of the circuit 11 provides the ability to independently select the read and write functions/operations utilizing e.g. read and write circuits 38, 40, such that read and write circuits 38, 40 can be selected to operate separately or together (e.g., simultaneously). The RWW function enhances existing capabilities of disk drives, and improves processing and performance. Further, the RWW function provides cost-effective versatility that can not be duplicated with a single IC conventional preamplifier.~~

The disk drive 24 can self-servo write when the preamplifier 88 is configured for the servo write mode and the RWW mode. For example, the disk drive 24 reads a reference pattern from one disk surface 52 using one transducer head 42 while writing servo patterns to one or more blank disk surfaces 52 using one or more other transducer heads 42. The reference pattern provides position and timing information for writing the servo patterns. As a result, the disk drive 24 self-servo writes with the absolute reference that a servo writer offers. The disk drive 24 can self-servo write in a variety of ways, including a bank write and a stagger write. Likewise, the reference pattern can be provided on the disk surface 52 in a variety of ways, including magnetic printing (printed media) and spin stand writing.~~In one example, a disk drive 25 including the circuit 11 provides self-servo write with absolute referencing that a servowriter offers. The disk drive 25 includes the ability to stagger or bank~~

~~write by reading real-time position and timing information while writing servo patterns. The circuit 11 provides such capability by allowing reading a reference pattern from a reference surface of a disk using one selected head while writing servo patterns on one or more blank disk surfaces using one or more selected heads, simultaneously. For example, one head 27 is selected for reading a reference pattern for providing position and fundamental timing information for servo patterns to be written simultaneously on an adjacent head or heads. Many methods of self-servowriting can be adapted to be more efficient and more accurate using the circuit 11. A few examples of improved self-servo-writing according to the present invention are described below. Other examples are possible and are contemplated by the present invention.~~

~~One such method is read-while-write self-servo-write using a reference disk. This method of self-servowriting incorporates the use of e.g. a magnetic printed media surface that includes both timing and radial position information (self-servo patterns).~~ FIG. 6 shows a ~~highly diagrammatic representation of an embodiment of a~~ magnetic printing station 140 that ~~for~~ magnetically prints~~ing~~ a reference pattern 142 on the reference disk 40A ~~reference disk storage surface with a servo reference pattern. a magnetic printing station 70 magnetically prints or otherwise transfers a servo reference pattern 72 to one surface 74 of a magnetic disk 76, known as a reference disk.~~

~~The magnetic printing station 70~~ using ~~can~~ a ~~utilize one of several known~~ magnetic transfer process~~es~~. The reference disk 40A is initially blank. The magnetic printing station 140 then ~~One such process includes the steps of~~ applies~~ying~~ a unidirectional magnetic domain orientation to the reference ~~a blank storage~~ disk 40A~~, such as the surface 74 of the disk 76~~. Next~~Then~~, a reticle or magnetic die with~~having~~ the ~~desired magnetic~~ reference pattern 142 is placed int~~o~~ close proximity to ~~with the storage surface 74 of~~ the reference disk 40A~~76~~, the reference disk 40A is heated to approach the Curie temperature of its storage media, and the reference disk 40A is selectively remagnetized at the disk surface 52A with the aid of a reverse bias field and localized heating to provide the reference pattern 142 on disk surface 52A in accordance with the reference pattern 142 established by the reticle or die. ~~and the disk 76 is heated to approach the Curie temperature of the storage media on the surface 74. The reference surface 74 is selectively remagnetized with the aid of a reverse bias field and e.g. localized heating in accordance with the reference pattern established by~~

~~the reticle or die.~~ Alternatively, if an optical reticle is used, a laser beam causes intense local heating through reticle apertures to provide magneto-optic selective domain magnetization at the disk surface 52A. In any case, the reference pattern 142 is printed on the reference disk 40A at the disk surface 52A.

~~In cases where an optical reticle is used, intense local heating through reticle apertures can be obtained from a laser beam, for example, in accordance with well understood magneto-optical principles in order to provide selective magnetization of domains of the reference-patterned surface 74 in accordance with the servo reference pattern 72.~~ Care must be taken during the magnetic printing process not to damage or contaminate the reference disk 40A~~76~~. Preferably, ~~although not necessarily,~~ the magnetic printing process occurs~~is carried out~~ in a very clean environment within the~~a~~ disk manufacturing process.

FIG. 7 shows the reference pattern 142. The reference pattern 142 includes circumferentially spaced spokes that extend radially from the inner diameter (ID) to the outer diameter (OD) of the reference disk 40A.

FIG. 8 shows the reference pattern 142 in more detail. The reference pattern 142 includes the sector spokes 144 that each include a single reference spoke 146 and multiple transfer fields 148. Thus, the adjacent reference spokes 146 are separated by multiple transfer fields 148.

The reference spokes 146 each include a DC field, an AGC field, a sync field, a gray code field and a servo burst quadrature pattern field. The gray code includes binary coded location by cylinder number that provides coarse head position information, and the servo burst quadrature pattern includes A, B, C and D servo bursts that provide fine head position information. The transfer fields 148 each include a servo burst pseudo-quadrature pattern field with A1 and B1 servo bursts that provide fine head position information. The gray code is used for long (coarse) seeks, the gray code and the servo burst quadrature pattern are used for short (fine) seeks and track-following, and the A1 and B1 servo bursts are used for track-following maintenance between the reference spokes 146. Furthermore, the gray code and the servo burst quadrature pattern provide absolute position information.

The reference spokes 146 have the same circumferential length (time) as the transfer fields 148. Furthermore, the reference spokes 146 and the transfer fields 148 provide position and timing information (transfer timing) for self-servo write. The transfer timing can be embedded to create the transfer fields 148 on another disk surface 52 for overwriting the reference spokes 146 with the (final) servo patterns, and the transfer timing fundamental frequency can be 10t where 1t is the bit cell of the servo patterns.

FIG. 9 shows the disk drive 24 in a self-scan station 150 after the disk drive 24 is assembled and before self-servo write. The disks 40 include the reference disk 40A and the data disks 40B, and the disk surfaces 52 include the disk surface 52A and the disk surfaces 52B. The disk surface 52A is the top surface of the reference disk 40A, and the disk surfaces 52B are the bottom surface of the reference disk 40A and the top and bottom surfaces of the data disks 40B. At this stage, the disk surface 52A includes the reference pattern 142 and the disk surfaces 52B are blank. Thus, the data disks 40B are blank.

The disk drive 24 is assembled before it is placed in the self-scan station 150. The magnetic printing station 140 prints the reference pattern 142 on the reference disk 40A, and then the reference disk 40A and the data disks 40B are~~The reference disk 76 is placed in a disk stack, and is used to recalibrate timing and position before each servo write. Referring to FIG. 7, after the servo reference pattern 72 has been applied to storage surface 74 of the printed disk 76, the disk 76, along with other blank disks 29 are~~ assembled onto the~~a~~ hub 46. ~~spindle 80 of a disk drive 25. The spindle 80 is mounted within an enclosed head-disk assembly (HDA) 28, and is rotated at a predetermined angular velocity by a spindle motor 23. A comb-like head actuator structure 37 is included with the HDA 28, wherein the head actuator structure 37 includes head arms 90 rotated by e.g. a rotary voice coil motor 92 in order to position transducer heads 27, respectively, adjacent to the reference surface 74 of the disk 76 and blank surfaces 98 of the disks 29.~~

After the disks 40~~76, 29~~ and the transducer heads 42~~27~~ are installed in the HDA 28, the HDA 28 is enclosed by a cover to prevent unwanted particulate contamination. The ~~A~~ drive controller ~~electronics module 26, such as a printed circuit board carrying large scale integrated circuits and other components,~~ is mechanically attached to the HDA 28 and is

electrically connected to the HDA 28 ~~thereto~~ by a suitable interconnection 152~~02,~~ ~~in order~~ to complete the assembly of the disk drive 24~~5~~.

–The disk drive 24~~5~~ is then placed in~~to~~ the~~a~~ self-scan station~~chamber~~ 150~~04~~ which ~~and connected to a suitable power supply~~provides a stable mounting structure, thermal stability, a suitable power supply and an interface bus. A personal computer (not shown) downloads test firmware into the disk drive 24, and ~~, wherein~~ a control and status collection computer- (not shown) collects data on ~~concerning~~ the disk drive 24~~5~~ during self-scan procedures. In addition, the drive controller 26 contains

~~In one version of the present invention,~~ a self-servo write ~~special~~ program that enables the disk drive 24 to self-servo write precise final servo patterns while the disk drive 24 is in the self-scan station 150~~in the drive controller electronics 26~~. The self-servo write program is ~~(e.g.,~~ resident in the ROM 62~~memory 305 (FIG. 3)~~ or downloaded from the control and~~a~~ status collection computer.

~~) enables a head 27 to read the reference pattern 72, and in turn enables one or more other heads 27 to write precise servo patterns on each storage surfaces 98 in accordance with a final servo pattern features plan. After all of the surfaces 98 of the disks 29 have been written with final servo patterns, the reference pattern 72 is overwritten, either in the self-scan station 104, or later with user data when the disk drive 25 is installed in a user computing environment for data storage and retrieval operations.~~

~~Referring to~~ FIG. 10~~8~~ shows self-servo write by the disk drive 24. The drive controller 26 sends configuration information to the preamplifier 88 that designates the servo write mode and the RWW mode, selects the transducer head 42 corresponding to the disk surface 52A for reading and selects the other transducer heads 42 for writing. The read selected transducer head 42 reads the reference pattern 142 from the disk surface 52A and generates a read signal that includes circumferential position information and radial position information for the transducer heads 42, thereby providing an absolute reference for the transducer heads 42. The servo processor 66 uses the position information to position the transducer heads 42, and the pattern generator 58 uses the position information to generate the servo patterns. As~~in conjunction with FIG. 7, in a self-servo writing method using the~~

~~drive controller electronics 26 including an embodiment of said circuit 11, the timing and position information of reference pattern 72 is read from the reference disk 76 via one head 27 and the information is processed by: (1) a position control process executed by the processor 110 and (2) a pattern generator process 112 , (e.g., instructions stored in memory 305) within the drive controller electronics 26. Simultaneous~~ the read selected transducer head 42 reads the reference pattern 142 from the disk surface 52A, the servo processor 66 positions the transducer heads 42, the pattern generator 58 generates the servo patterns and the other transducer heads 42 write the servo patterns to the disk surfaces 52B. Thus, the reference pattern 142 is read while the servo patterns are written.

Advantageously, the reference pattern 142 enables the servo processor 66 to recalibrate timing and position for the transducer heads 42 before each servo pattern write ~~with reading the reference pattern 72 from the reference disk 76 via a selected head 27, a servo pattern is written to surfaces 98 of one or more other disks 29 via one or more other heads 27 under control of a servo write process executed by the processor 110~~, thereby using real-time position and timing information to write~~generating~~ the servo patterns as cohesive cylindrical ~~timing/~~servo wedges on the disk surfaces 52B, and avoiding timing/speed variations that occur between conventional switched-out servo read and write operations~~other disks 29. In FIG. 8, a head 27 is utilized per disk surface (designated as heads 27_x to indicate multiple heads 27 in FIG. 8, wherein 'x' is a head index).~~

. The reference pattern 142 also enables the pattern generator 58 to simultaneously ~~The method provides self-servo writing with absolute radial and circumferential referencing of conventional servowriters, but without disadvantages of the conventional servowriters. The disk drive 25 staggers or bank writes the servo patterns on surfaces 98 of disks 29 using real-time position and timing information from the reference disk 76 during the servo write process. The circuit 11 allows reading timing/position information 72 from the reference disk 76 on one head 27 while simultaneously writing servo patterns on surfaces 98 of one or more disks 29 using one or more other heads 27.~~

~~Specifically, in one example, in self servowrite using RWW mode, the circuit 11 is configured by information transmitted to the registers 60, 62, 64 therein, for the mode control 41 to select and enable: (1) one read circuit 38 in Read Mode to read the reference pattern~~

~~72 via a corresponding read head 27, and (2) one or more write circuits 40 are selected for Write Mode (or alternatively Servowrite Mode) to write a servo pattern on surfaces 98 one or more disks 29 via one or more selected heads 27.~~

~~Head selection via register 60 is performed to select a read head 27, and Servowrite Mode selection via register 64 is performed to select one or more write heads 27 for writing servo patterns, whereby effectively the read head 27 is mapped out from writing during self-servo write operation. This allows the read head 27 to read the reference pattern 72 from the disk 76 and provide the timing and position information back to the disk drive controller electronics 26 for processing, and simultaneously writing servo patterns on surfaces 98 of disks 29 via write heads 27, without disturbances from the writer elements of the dedicated read head 27. In this way, the drive controller electronics 26 can~~ clock out the servo patterns ~~on one or more disks 29~~ in the same manner as a clock track.

~~The reader element of the read head 27 reads the reference pattern 72, and provides a read head signal 114 to the read/write channel 32 (including an AGC/Filter circuit 304, servo demodulator 306 and pulse detector 308). In the self-servowrite RWW mode, the read/write channel 32 utilizes the read signal 114, and resolves timing information 114A and position information 114C (periodically) from the read signal 114. The read/write channel 32 decodes position information 114C and timing information 114A from the reference pattern 72 by e.g. either amplitude (i.e., standard burst demodulation) or interval (i.e., phase angle position) to hold accurate head placement and simultaneously write servo patterns to the disks 29 using write heads 27. In this way, the disk drive 25 in effect functions equivalent to a servowriter. In another version, disk drive firmware comprising programmed logic or control instructions (e.g., resident in memory 305 in FIG. 3) resolves the read signal 114 into the position and timing signals 114C and 114A, respectively. Other versions are possible and contemplated by the present invention.~~

~~In either case, after servo patterns are written to the disks 29, the read head 27 can be selected in Write Mode to overwrite the reference pattern 72 on disk 76 with a servo pattern such that the disk 76 can be used for storing user data. Preferably, at least two circuits 38 and/or 40 are selectable in the RWW mode such that the reference surface 74 of reference disk 76 can be overwritten in the same manner after the servo pattern has been~~

~~recorded to the other disk 29.~~

~~Unlike the present invention, conventional self-servo write processes do not provide for multiple tasking in reading a reference pattern 72 from a disk 76 while writing servo patterns on one or more disks 29. Conventionally, reading a reference pattern 72 from the disk surface 74 via a read head 27 is sequentially followed by switching to other heads 27 to write a servo pattern on an disk 29, wherein the read and write operations are mutually exclusive (i.e., not overlapping or simultaneous). As such conventionally, the reference pattern 72 is read for a time period via one head 27 to obtain timing and head position information, and for a following time period the timing and position information is utilized to position another head 27 and write the servo pattern on a disk 29 (e.g., a wedge). The conventional self-servo write process switches between reading and writing until the entire servo pattern is written out on a disk 29.~~

~~By contrast, in a self-servo write using RWW process according to the present invention, there is no need to switch out of the reference pattern 72 Read Mode to write servo patterns on disks 29. As such, the reference information (e.g., timing and position information 114A, 114C, respectively) obtained from the read signal 114 from the reference disk 76 via one head 27 are used to simultaneously clock out servo patterns to other disks 29 on other heads 27. Further, any timing errors (e.g., due to rotation speed variations) are compensated for in real-time. The disk drive 25 accounts for rotation speed variations by correcting timing errors while a servo pattern is being written, to efficiently generate an accurate servo pattern, without need for repeating servo writes due to e.g. timing/speed variations between reference read servo and write operations which negatively affect said conventional methods.~~

~~In self-servo-write method, the circuit 11 is configured by information transmitted to the registers 36 therein, to select e.g. read circuit 38 and corresponding head 27 for reading timing and position information (i.e., Read Signal 114) from the reference surface 74 of the reference disk 76. The reference information provides head position and timing information to the servo controller 34 (FIG. 3) for positioning write heads 27 as necessary for writing servo patterns. Said position and timing information are processed by the write clock pattern generator process 112 and the servo/position control processor 110 within the drive~~

~~controller electronics 26 (e.g., servo controller 34). For writing servo patterns, head positioning information 116 is generated by the servo processor 110, and servo pattern information 118 is provided by the pattern generator process 112.~~

FIG. 11 shows a head position servo loop 154 of the disk drive 24. The read selected transducer head 42 generates a read signal that includes position and timing information in response to reading the reference pattern 142. The servo demodulator and ADC 80 resolves the position and timing information in the read signal and provides a position signal that indicates the current position of the transducer head 42. The servo processor 66 subtracts the position signal from a desired head position to provide a modified position signal based on the difference. The DAC 84 converts the modified position signal into an analog position signal that the driver 86 uses to drive the actuator 50. The head position servo loop 154 is used during self-servo write to maintain accurate position control of the transducer heads 42 over the disk surfaces 52.

FIG. 12 shows the disk drive 24 generating the servo patterns for self-servo write. The pattern generator 58 includes a pattern memory 156 and a shift register 158. The pattern memory is a random access memory (RAM), and the shift register 158 is a serial shift register with parallel load.

The mode controller 90 selects the transducer head 42 for reading the reference pattern 142 from the disk surface 52A and the transducer heads 42 for writing the servo patterns to the disk surfaces 52B in response to configuration information from the servo processor 66. The read selected transducer head 42 generates a read signal by reading the reference pattern 142 on the disk surface 52, and the read signal is sequentially processed by the preamplifier 88, the AGC/filter 74 and the pulse detector 76. The clock multiplier and PLL 60 phase locks on the read signal from the pulse detector 76 based on the timing frequency of the transfer fields 148 and clocks the shift register 158 at the maximum servo pattern frequency. As a result, the servo patterns are synchronously clocked to rotational speed variations of the disks 40.

The servo processor 66 provides track-to track positioning and track following for the transducer heads 42 using the reference spokes 146, and provides track-following

maintenance between the reference spokes 146 using the transfer fields 148.

When the read selected transducer head 42 stabilizes over a starting position on the disk surface 52A, the pattern memory 156 loads the servo pattern into the shift register 158 as a series of 1's and 0's, and the servo pattern generation sequence begins. Thus, the servo positioning operates simultaneously with the servo pattern generation and self-servo write.

FIG. 13 shows a flow diagram for self-servo write. In this example, the disk drive 24 includes one reference disk 40A and three data disks 40B, and therefore one disk surface 52A (on the reference disk 40A) that includes the reference pattern 142 and seven disk surfaces 52B (on the reference disk 40A and the data disks 40B) that are blank. Likewise, the disk drive 24 includes one transducer head 42 corresponding to the disk surface 52A and seven transducer heads 42 corresponding to the disk surfaces 52B. In addition, the reference pattern 142 includes the reference spokes 146 each followed by seven transfer fields 148.

During self-servo write, the (final) servo patterns 160 are written to the disk surfaces 52B in a stagger pattern. The reference spoke 146 is read to position the transducer heads 42, then the servo pattern 160 is written on the first disk surface 52B as the first transfer field 148 following the reference spoke 146 is read to position the transducer heads 42, then the servo pattern 160 is written on the second disk surface 52B as the second transfer field 148 following the reference spoke 146 is read to position the transducer heads 42, and so on, until the seventh servo pattern 160 is written on the seventh disk surface 52B as the seventh transfer field 148 following the reference spoke 146 is read to position the transducer heads 42. The process then repeats for the next reference spoke 146 and transfer fields 148.

The final servo patterns 160 are arranged in a stagger pattern in which sequential servo spokes are offset from one disk surface 52B to the next. Furthermore, position error due to disk flapping can be updated as a transducer head 42 writes to a disk surface 52B by another transducer head 42 that reads the servo patterns from the opposite disk surface 52B. Likewise, a transducer head 42 can provide track centering as another transducer head 42 writes the servo patterns 160.

This example includes the following parameters:

Sector spoke density = 100 sector spokes per revolution

Reference spoke density = 1 reference spoke per sector spoke

Transfer field density = 7 transfer fields per sector spoke

Disk rotational speed = 6000 rpm = 10 mS per revolution

Sector spoke time = (10 mS)/(100 sector spokes) = 100 uS per sector spoke

Reference spoke time = (sector spoke time)/8 = 12.5 uS per reference spoke

Transfer field time = (sector spoke time)/8 = 12.5 uS per transfer field

~~The RWW preamplifier circuit 11 enables real-time and/or ultra high bandwidth closed loop operation (e.g., for self-servo write) that can not be accomplished with a conventional drive preamplifier. Referring to~~ FIGS. 14~~9~~A-14B show~~,~~ a flowchart ~~an example process~~ for self-servo write by the disk drive 24 ~~using a printed media reference pattern is described. The process controls the orientation of magnetic domains to create a final servo pattern that is concentrically and radially arranged on a magnetic recording surface 98 that is typically used in the manufacture of hard disk drives. The final servo pattern includes position and timing information that is used by the drive mechanical, electrical and control system to establish absolute radial and circumfrential placement of its transducer heads.~~

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The reference pattern 142 is printed on the reference disk 40A ~~As described above in relation to FIGS. 6-7, creating a printed media reference surface 74~~ (step 200), ~~t can be accomplished in several ways. One example is to place a mask onto a magnetic surface that has all of its domains oriented in one direction. The mask is made of magnetic shielding material and is affixed to a surface of the media disk 76. A magnet of opposing orientation is passed over the masked surface of the media, and causes the unmasked areas of the media to invert their orientation. The domain orientation differences are read by a transducer head as flux transitions, and are used in a drive for timing and amplitude metrics.~~ The reference disk 40A ~~76~~ is installed into the disk drive 24~~25 during the assembly process~~ (step 202), the ~~and~~ drive controller 26~~electronics 26~~ is installed into the disk drive 24~~included~~

~~therein~~ (step 204), and after ~~. When~~ the ~~drive~~ assembly is complete, the disk drive 24~~5~~ is placed in the~~installed into a~~ self-scan station 150~~chamber 104~~ (step 206)~~ that provides a stable mounting structure, thermal stability, power and an interface buss that can be connected to a PC for loading a test process firmware into the drive 25~~.

~~———~~T~~After~~ the disk drive 24~~5~~ is powered up (step 208) and spins up (step 210) to a programmed~~/desired~~ disk rotational speed (steps 212 and~~,~~ 214), and then ~~the~~ self-servo write ~~process can~~ begins (step 216).

The servo processor 66 controls self-servo write by executing instructions (firmware) resident in the ROM 62, and t~~— The self-servo write process is controlled by the processor 110.~~

he r~~R~~egisters 64~~35~~ are loaded with ~~in the controller 34 are setup to contain information for the processor 110 to use for the self-servowrite process. The registers 35 are loaded with~~ the number of spokes, number of heads, ~~length of reference spokes,~~ number of transfer fields, number of tracks, length of spokes, length of transfer fields, head width~~,~~ ~~total number of tracks,~~ and other pertinent information ~~to complete the process. In one example, the self-servo write process is executed by the processor 110 from instructions (e.g., firmware) resident in a memory/ROM 305~~ (step 218)~~, as follows~~. The transducer heads 42~~27~~ are moved to position the transducer ~~a~~ head 42 corresponding to the disk surface 52A ~~27~~ over the reference pattern 14~~7~~2 (step 220), and the servo processor 66 sends~~ and based on control/~~ configuration information to the mode controller 90 that set~~signals from the processor 110, the control 41 plac~~es the preamplifier 88~~circuit 11~~ ~~in~~in the ~~normal~~ r~~R~~ead m~~M~~ode ~~(described above)~~ (step 222) and selects the transducer head 42 corresponding to the disk surface 52A for reading~~. Accordingly, the control 41 enables a transducer head 27 that corresponds to the printed media surface 74~~ (step 224)~~, and the reference information 72 is read via the selected read head 27 to generate the read signal 114~~.

~~——— FIG. 10A shows an example of servo position information composite of the reference pattern 72 on the reference surface 74. The reference pattern 72 includes a plurality of concentric tracks, each including reference spokes 122 with a multiplicity of transfer fields 124 therebetween. The reference spokes 122 in concentric tracks form radial spokes. The FIG. 10A example shows several transfer fields 124 between two reference spokes 122.~~

~~Each reference spoke 122 includes gray code (I), and servo burst quadrature pattern (II) of servo bursts A, B, C and D. The gray code is a binary-like coding system that is part of the reference pattern 72 and contains coarse position information, and the amplitudes of servo bursts A, B, C and D provide fine head position information. Each transfer field 124 includes servo burst pesudo-quadature pattern (III) A1, B1, for on track head positioning. FIG. 10C shows further details of spokes 122 and transfer fields 124, providing position and timing information (e.g., transfer timing). In another example there can be on transfer field 124 between a pair of spokes 122, wherein the transfer field includes multiple pairs of servo burst pseudo-quadrature patterns A1, B1.~~

~~Referring to FIG. 10B, the position and timing information in reference pattern 72 induces the read signal 114 in the read head 72, wherein as described above the read signal 114 includes the position signal 114C and the timing signal 114A. The A/D circuit (servo demode) 306 in the channel 32 resolves the position information signal 114C and the timing information signal 114A from the read signal 114. The position control processor 110 uses the position information 114C as it is read by the selected head/sensor 27 from the reference pattern 72, as feedback during the RWW self-servowrite process to determine the current head position. The current head position is then subtracted from the desired head position by the processor 110 and a position *command* is issued based on the difference. The position *command* is output through a servo control interface 302 as digital position data 116 and is converted to an analog signal in the power electronics driver 119 which drives the VCM 92 in the HDA 28. This method is utilized during self-servo writing to maintain accurate position control of the write head 27 over the disk surface 29.~~

~~Referring back to FIGS. 9A-B, ~~Tthe servo processor 66~~110~~ waits for a pattern sequence that initiates a servo lock attempt, and i~~.~~ ~~I~~f the data ~~that~~ follows ~~is~~ a~~what~~ is expected, the~~an~~ initial servo lock occurs~~is complete,~~ and the absolute position is attempted to be acquired- by reading the gray code ~~d region~~ of the reference spoke 146~~22 (FIGS.10A, 10C, 'Cyl. #')~~ (step 226). Once the absolute position is acquired, the head position servo~~control~~ loop 154 is closed ~~(e.g., FIGS. 10A-B)~~ (step 228) and ~~is commanded to~~ moves the ~~a write~~ transducer heads 42 to the 'start ~~servowrite'~~ position ~~on at least one disk surface 98~~ for reading the reference pattern 142 from the disk surface 52A and writing the ~~final~~ servo patterns to the disk surfaces 52B~~thereon~~ (steps 230 and~~,~~ 232).

When the read selected transducer head 42 is stabilized over the starting position on the disk surface 52A, the pattern memory 156 loads the servo pattern into the shift register 158 and the servo pattern generation sequence begins (step 234). The clock multiplier and PLL 60 phase locks to the timing reference frequency of the transfer fields 148 (steps 236 and 238). Thereafter, in response to the configuration information from the servo processor 66, the mode controller 90 sets the write currents for the transducer heads 42 (step 240) and selects the transducer heads 42 for writing the servo patterns to the disk surfaces 52B (step 242). The mode controller 90 receives configuration information that sets the preamplifier 88 to the RWW Mode (step 244) and the servo pattern is synchronized with the index reference spoke 146 (steps 246 and 248). A reference spoke counter is loaded with the number of reference spokes 146 per revolution of the disk 40A (step 250). When the read selected transducer head 42 reaches the end of a reference spoke 146 (step 252), a write selected transducer head 42 is enabled (step 254), a transfer field counter within the registers 64 is loaded with the number of transfer fields 148 between each pair of reference spokes 146 (step 256) and the read selected transducer head 42 reads the transfer field 148 (step 258).

~~FIG. 11 shows an example diagram for generating a final servo pattern signal 118. Referring to FIGS. 9A-B in conjunction with FIG. 11, when the transducer 27 is stabilized over the starting position on at least a disk surface 98, the pattern generator 112 (FIG. 11) loads a 'final servo pattern' (e.g. from a memory 39) into a shift register 126 as a series of 1's and 0's (step 234), and the pattern generation sequence begins. The clock multiplier PLL 111 is phase locked to the signal 114A (the timing frequency of the transfer field 124 in FIG. 10C) (steps 236, 238). Thereafter, in response to configuration signals from the processor 110, the control 41 sets write currents for write heads 27 (step 240), and selects write heads 27 for writing the servo pattern 118 on disk surfaces 98 (register 64, FIG. 2) (step 242). The control 41 selects RWW Mode for the circuit 11 (step 244), and self servo write pattern is synchronized with reference spoke index 122 (steps 246, 248). A spoke counter is loaded with the number of spokes 122 per revolution of disk 76 (step 250). When the read head reaches the end of a reference spoke 122 (step 252), the selected write head 27 is enabled (step 254), a transfer field counter (e.g., within registers 35) is loaded with the number of transfer fields 124 between each pair of reference spokes 122 in the pattern 72 (step 256), and the read transducer reads a transfer field in the reference pattern 72 (step 258).~~

~~The servo positioning according to FIGS. 10A-B operates in overlap or simultaneous mode with the pattern generation and write operation according to FIG. 11. Servo positioning by processor 110 is accomplished by reading and processing the amplitude of the A1 and B1 servo bursts of the transfer pattern 72 as shown in FIGS. 10A-B. The A1 and B1 bursts are used only for on-track center maintenance between the reference spokes 122. The reference spokes 122 include absolute position information (i.e. gray code and four burst quadrature), and are used for track to track positioning. Pattern generation is accomplished per example of FIG. 11 and can be traced through using the signal 114. The timing signal 114A is used for pattern generation (e.g., FIG. 11), and the position signal 114C is used for servo positioning (e.g., FIGS. 3, 10B and 11).~~

The ~~Referring back to FIGS. 9A-B, an example~~ servo positioning (steps 260-264) occurs simultaneously ~~and parallel~~with the servo ~~/overlapping~~ pattern generation and self-servo write ~~process as controlled by the processor 110 is described~~ (steps 266-274).

–After reading the~~a~~ transfer field 1248 (step ~~-in step~~ 258), the ~~in a servo positioning process, the read~~ transducer heads 422~~7~~ are~~is~~ maintained on the track center (on-track) of the ~~a~~ transfer field 148 (step 260) by reading ~~and processing~~ the amplitudes of the A1 and B1 servo bursts in~~of~~ the transfer pattern 148, determining t~~as shown in FIGS 10A-B, wherein A1 and B1 are used for on-track center maintenance between the reference spokes.~~ The difference between the amplitudes ~~read head sensed amplitude of A1 and B1 (A1-B1) is measured~~ (step 262)~~,~~ and adjusting the position of ~~wherein if the difference A1-B1 is not zero, then~~ the transducer heads 42 based on the difference~~position is adjusted~~ (step 264). S~~The s~~teps 262 and~~,~~ 264 are repeated to maintain the transducer heads 42 on the track center of the transfer field 148.

~~Once the head is on track center, the gray code in the reference spoke is read (step 276) and a determination is made if the head is on the proper track number (step 278). If so, the spoke counter is decremented by one (step 280), wherein when the spoke counter shows zero, indicating that all spokes on the current track have been processed (step 282), the head is moved to the next radial track position (step 284). To process the remaining tracks of the reference pattern 72, the positioning process proceeds to step 246.~~

After ~~In a simultaneous or overlapping pattern generation and servo write process under control of the processor 110, after~~ reading the ~~each~~ transfer field 12~~4~~8 (step 258), and while servo ~~from the disk 76 and~~ positioning ~~of~~ the transducer~~read and write~~ heads 42, the ~~a corresponding final~~ servo pattern is written by the write selected transducer head 42 to the corresponding disk surface 52B (step 266) until the end of the transfer field 148~~118 is written on each disk surface 98 via a corresponding write head. Specifically, each transfer field is read from the disk 76 via a read head (step 258), a corresponding final servo pattern is written via a selected write head on a disk surface 98~~ (steps ~~266,~~ 268). Thereafter, the next write selected transducer head 42 is switched to ~~, the process selects the next write head in sequence for the next surface 98 of a disk~~ (step 270) and ~~, decrements~~ the transfer field counter is decremented by one ~~by one~~ (step 272) to determine whether all the transfer fields 148 between the pair of reference spokes 146~~, and if the transfer field counter is not zero~~ have been read (step 274). If not, ~~,~~ the process return~~proceeds~~ ~~back~~ to step 258 and the next transfer field 148 is read~~for reading the next transfer field and writing a final servo spoke 128 (in servo pattern 118) using said next selected write head to a corresponding disk surface 98. Steps 258 through 274 are repeated in a loop for all transfer fields 124 between each pair of reference spokes 122. Once all transfer fields 124 between a pair of reference spokes 122 have been so processed, the pattern generation and servo write process proceeds to step 276 for processing remaining reference spokes on the current track of the reference pattern 72~~.

Once the transducer heads 42 are on-track (step 262) and all the transfer fields 148 between the pair of reference spokes 146 have been read (step 274) the gray code in the reference spoke 146 is read (step 276) to determine whether the transducer heads 42 are at the proper track (step 278). If not, the process returns to step 230 to position the transducer heads 42 at the proper track, otherwise the reference spoke counter is decremented by one (step 280) to determine whether all the reference spokes 146 on the current track have been read (step 282). If not, the process returns to step 252 to read the next reference spoke 146, otherwise the transducer heads 42 are moved to the next track (step 284) to determine whether all the tracks have been written to (step 286). If not, the process returns to step 246, otherwise the process proceeds to self-scan ~~In the example pattern generation process of FIG. 11, once the index reference spoke 122 is~~

~~detected and the first transfer field begins, the clock multiplier 111 'out' is enabled. The read signal 114 via circuit 11 is processed by channel 32 (AGC 304 and pulse detect 308) to generate the timing signal 114A for the clocking the serial shift register 126. The pattern of 1's and 0's from the register 126 is processed by the preamplifier circuit 11 to control the direction of current through the selected 'write' transducer heads. The current through a transducer head is changed from one direction to the other causing the polarity of the media magnetic domains to change within the effective field. The series of transitions on each surface 98 are the final product spoke 128 (this process is graphically depicted as the closed loop operation in FIG 11). In this example, the final spokes 128 are placed onto different disk surfaces 98 in a stagger pattern depicted by example in FIG. 12, wherein the disk assembly comprises a reference disk 76 and three data disks 29, the reference disk having a reference surface and a blank surface 98, and each of the three data disks having two opposing blank surfaces 98. Each disk surface has a corresponding head 27 (total of eight heads). In the example of FIG. 12, a read head 27 (e.g., HDn) is positioned to read the reference pattern 72 from disk 76, and each of a plurality of write heads 27 (e.g., HDn+1 through HDn+7) is positioned to write final servo patterns on a surface 98 of a disk 29. There are seven transfer fields between each pair of reference spokes in the reference pattern 72, and steps 258-274 are repeated for each transfer field. This process is repeated for all tracks until all of the tracks are written across the surfaces of disks 29. In another example the final servo spokes 128 are placed onto different disk surfaces 98 in a bank write.~~

~~Once all tracks of the reference pattern 72 have been processed (step 286), a self-scan process~~ (step 288) ~~begins as described further below. If in step 278 the head is not on the proper track number, the servo positioning process proceeds back to step 230 to move the head(s) to proper start position. If in step 282 all the spokes and transfer fields for the current track have not been processed, the positioning process proceeds to step 252 to process the next spoke.~~

~~As such, referring to FIGS. 8, 10A-C and 11, the position control processor 110 and the clock and pattern generation process (circuit) 112 allow dissection of the reference information 72 read from the reference disk 76 to select the portion of reference pattern data to analyze (e.g., position/timing information). In one embodiment, the position control~~

~~process comprises a logic circuit implemented in an ASIC or a process executed by processors (e.g., processor 110) within the controller ASIC 34 of the drive controller electronics 26. Position is maintained by servo-burst equalization shown by example in FIGS. 10A-B. Any timing errors are erased and rewritten until they are within acceptable tolerance, such that timing remains coherent across entire surface 98. The reference read frequency is phase locked to the pattern generator clocking frequency thus keeping the servo pattern synchronously locked to the rotational speed variations caused by the spindle motor control error (e.g., FIG. 11). The clock signal 114A provides the timing for the clock multiply circuit 111 which provides the timing and frequency for the pattern generator circuit 112. The process/circuit 112 under firmware control generates the servo pattern data 118. Because the read reference signal 114 is read simultaneously while writing final servo patterns, the servo pattern data 118 written to each surface 98 is synchronized to the rotational speed of the disks 29. The relationship between signals 114 and 118 is closed loop due to the RWW function of the circuit 11.~~

~~Disk flapping modes (i.e. mechanical distortions to a flat disk surface caused by rotational and axial excitation) can cause unwanted disturbances. RWW according to the present invention can take advantage of the spoke stagger (sequential spoke offset from one surface to the next) from head to head. Specifically, for each disk having two opposing surfaces 98 and two corresponding heads 27, a position error can be updated when a head 27 is writing on one surface, by reading the servo information on the opposite disk surface 98. The radial movement detected by the opposite head is the inverse of the other head. This information can be used for write-position correction, or as a write error detection. Further track centering on one head while writing on another can be performed actively.~~

~~Further, self-servowriting using magneto-resistive type transducer (MR) including a writer element and a reader element, is made simpler by the present invention because it is not necessary to compensate for the reader element offset from the writer element in the same head 27. The dedicated read signal from a read head 27 is a relative reference for radial position, and an absolute reference for timing because timing is coherent from track to track. Position ultimately depends on each head's physical placement over the corresponding disk surface. The disk surface provides a relative reference in the same way that a servowriter uses an external reference to establish the radial location of the heads 27.~~

~~The offset difference between the final product servo wedges/spokes and the reference surface need only be compensated for during the reference-overwrite process. Once the tracks are placed, the transfer fields on the reference surface are transferred to obtain the product servo wedges in an absolute reference to the other tracks. However, due to the reader/writer element offset in a head, if a track is copied from a new reference track, the track is placed relative to the writer elements location which would slightly shift or offset the track location relative to the rest of the cylinders, thereby necessitating compensation. This offset can be reconciled during the reference surface overwrite process (reprocess) with a geometry normalization table or algorithm which accounts for the offset difference of absolute track placement due to use of the new reference surface and the physical reader/writer element offset difference of the head 27. For an example track density said offset can be more than 10 tracks.~~

~~In another aspect, the present invention provides a referenced media translation self-servo writing method. The disk drive assembly includes at least one reference disk with a reference surface having a reference pattern including fundamental timing (e.g., clock frequency) and position information. In a method different from the printed media reference disk above (FIG. 6), the reference pattern 72 is written on the surface 74 of the reference disk 76 e.g. using a spin stand writer. Thereafter, the media translation self-servo writing process using RWW circuit 11 according to the present invention is similar to that for a printed media reference disk described above for in relation to FIGS. 9A-B, 10A-C, 11, 12, and therefore is not repeated again.~~

~~The frequency of the reference pattern 72 is a multiple of the final servo pattern frequency to provide servo pattern timing. The position information can be provided using a standard modified servo/timing burst, or a time interval pattern (e.g., printed media) decoded as timing and position information. The time interval pattern provides position information using a phase tracking method rather than a burst amplitude demodulation. A time interval pattern is typically used on printed media (FIG. 6), but can also be generated using conventional head/media writing methods. In a time interval pattern, radial position is derived by equating a gap length to a radial location. There are two major fields to a time interval pattern: a Reference Field and a Chevron Field. The Reference Field includes series of radially coherent transitions that begin and end in an exact time period across the radial~~

~~stroke of the transducer 27 creating a reference domain (e.g., the first domain, 'index' begins at 0(t) and ends at (t)+10 micro seconds relative to the transducer 27 as it moves in any radial direction). The Chevron Field is a series of angularly coherent transitions relative to the Reference Field, where the beginning boundary is offset in distance from the ending boundary of the Reference Field creating an angular gap between fields across the radial stroke. The gap between the first field and the second field increases across the disk in a radial direction. Thus the phase of the range of the gap, delta(t), can be resolved as radial position and tracked electronically. i.e. (t)max - (t)min = delta(t) = 360 degrees.~~

~~An example reprocess method according to the present invention, referenced above, is now described. Theypically a disk drive 245 is must be reprocessed if it contains servo-written with a faulty servo pattern . Further the disk drive must be re-servo-written if the disk drive failed the final test for marginal reasons. Reprocessing is performed when a portion of the servo pattern that was written that needs to be erased before a new servo pattern can be placed. The present invention provides a self-reprocess method using RWW mode for self-reprocessing, wherein e.g. an error in self-servo write process requires erasure and re-writing of erroneous servo patterns. A controlled velocity read sweep locates residual data on disk surfaces 98 and indicates where the erroneous servo patterns needed to be erased. In one case, the MR reader of head(s) 27 is used to scan the disk surface 98 by performing an estimated velocity sweep with the reader enabled. Once erroneous data is located, the amplitude of that signal is used by the servo controller 110 to establish a position, and then that location is erased.~~

~~Conventionally reading and writing operations are mutually exclusive, and as such servo control for reprocess is performed using one head to find and assure erasure of the desired location. However, when performing head to head position referencing, the offsets between different heads have to be characterized and compensated first. The conventional process includes locating the erroneous servo pattern with a first head, switching to a second head, servoing, compensating and erasing with that second head. A disadvantage of the conventional method is that there must be servo data present for an alternate head that corresponds to the location of interest on the surface to be erased in order to properly place the erase head.~~

~~Referring to the example flow diagram in~~ FIG. 15~~3~~ shows a flow chart for ~~for~~ self-reprocessing faulty servo patterns by the disk drive 24. A controlled velocity read sweep across the disk surfaces 52 locates erroneous servo patterns ~~according to the present invention, the start position (e.g., track) of the area (e.g., old/erroneous servo pattern) to be erased is located on at least a disk surface 98~~ (step 290). The servo processor 66 sends configuration information to the mode controller 90 that sets the preamplifier 88 ~~circuit 11 is configured by servo processor 110, which transmits configuration information to the registers 36 of the circuit 11, such that the mode control 41 places the circuit 11~~ in the RWW m~~M~~ode (step 292). Then ~~, wherein~~ a selected transducer ~~first~~ head 42~~27~~ ~~is selected to~~ reads ~~residual~~ position information from the corresponding ~~a first~~ disk surface 52~~98~~ to provide servo positioning~~establish transducer radial position control~~ (step 294)~~,~~ while other transducer~~at the same time one or more~~ heads 42 ~~are selected to a~~ erase the servo patterns on the corresponding ~~one more~~ disk surfaces 52~~98~~ in ban~~e~~k or stagger form (step 296~~5~~). Thereafter, the selected transducer head 42 erases the servo patterns on the corresponding~~data on first~~ disk surface 52~~98 is erased using the first head~~ (step 298~~6~~) and ~~under control of the servo processor 110,~~ then the transducer heads 42 are ~~actuator~~ move~~d~~s ~~the head~~ to the next track ~~location of the area~~ to be erased (step 300~~297~~). If this track is the last track to be erased (step 302) then the process terminates (step 304), otherwise the process returns to step 294.

The disk drive 24 can perform self-reprocessing using a single transducer ~~, and repeats the above steps until all tracks in the erase area have been processed (step 298). In embodiments of the heads 27 comprising separate reader and writer elements (e.g., an MR head), the self-reprocess method can be utilized within the same~~ head 42~~27~~ by reading the servo patterns with the MR reader 110 to provide servo positioning ~~, wherein one reader element in the head 27 is utilized to read,~~ while ~~the write element in the head is used to~~ simultaneously writing with the writer 112 to erase the servo patterns using ~~e.~~

~~In the example self-reprocess using RWW method, the read signal is not disturbed by writing~~ a constant ~~current (~~DC erase current that does not disturb the read signal~~)~~. The MR reader 110 is in front of the writer 112 so that the servo patterns are read before being erased.~~This is true even while reading and writing on the same head. Servo and erase are all that is needed. All data can be erased because reading can be performed by a heads~~

~~reader element in front of the same head's writer element. Where data must be detected and erased across one or more disk surfaces 98, then servo reading can be performed on one head while bank erasing (e.g., erasing a plurality of disk surfaces) on other heads. There is no need to switch continuously from writing to reading and back again, resulting in a considerable time saving in the erase process (reprocess).~~

~~As such, in one example according to the present invention, reprocessing a disk drive is performed when there is a format failure. The failure can be for many reasons, but all or part of one or more disk surfaces 98 must be erased so that the disk drive can be re-written with new final servo spokes. Conventionally, the process of erasing previously written servo spokes is performed on a servowriter where the actuator 37 is controlled using an external positioning source. When self-servowriting, the erase process is difficult because tracks are being erased, and references are disappearing with each erase. It is especially difficult to erase using all heads via a conventional preamplifier. A RWW circuit 11 according to the present invention allows signals to be read on one head while erasing disk surfaces on the same head or on or more other heads. The process of controlling the actuator location using RWW Reprocess is similar to controlling the actuator in normal drive operations. With MR type heads where reader and writer transducers are separate, it is contemplated to read and erase (erase = DC write) on the same head. This makes the reprocessing process very efficient.~~

The preamplifier 88 provides the disk drive 24 with cost-efficient capability to perform self-servo writing, self-reprocessing, disk flapping negation while writing, track-centering while writing and calculating position error before transducer head switches.

The preamplifier 88 ~~circuit 11~~ can be implemented as an integrated circuit, ASIC or ~~IC,~~ firmware~~, etc.~~. In addition ~~to self-servo writing and reprocess examples described herein, the circuit 11 can be used for implementing other processes and functions within a data storage drive that can benefit from the functions provided by the circuit 11. Though in the description herein the circuit 11 has been designated as a preamplifier~~, the functions of the preamplifier 88 ~~circuit 11~~ can be implemented in other components ~~in the HDA 28, and/or the drive electronics 26~~ of the disk drive 24~~5~~. ~~Similarly, the controller 34 and the processor~~

~~110 can be implemented as an ASIC, IC or other logic circuit configured to perform the functions/processes described herein.~~

The configuration information can be sent from the disk controller 26 to the mode controller 90 in a variety of ways. For example, the servo processor 66 can send the configuration information from the ROM 62 to the interface register 92 via the serial interface 70 and the clock/data line 114 with the read and write operations gated by the R/W select line 116. In another example, the servo processor 66 can send the configuration information as a serial word on the R/W select line 116.

The channel 34 can be have its read circuitry independently selectable to be active or inactive during write operations, thereby providing independent operation of its read and write paths and supporting simultaneous read and write data streams.

~~Providing a disk drive with the capability to read and write data simultaneously to different data storage locations according to the present invention, is advantageous from many perspectives, for example test time reduction. As density increases test time also increases, necessitating the introduction of methods that are more time efficient. The Read-While-Write (RWW) functionality allows new methods to be used that would reduce test time in test process steps by as much as 50%. In another version, the disk drive 25 can include multiple circuits 11, wherein the RWW function allows each of the multiple of circuits 11 to perform simultaneous read and write functions.~~

The present invention has been described in considerable detail with reference to certain preferred versions thereof,~~;~~ however~~,~~ other versions are possible. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained herein.

Abstract

A ~~data transfer driver for a~~ disk drive includes ~~ing~~ recording media having one or more recording surfaces, one or more ~~data~~ transducer heads positionable relative to the recording surfaces by an ~~head position~~ actuator ~~structure~~ operating within a head position servo loop, and a data transfer driver. A ~~The data transfer driver includes a~~ preamplifier in the data transfer driver includes ~~having: a control interface for receiving configuration information to selectively transfer data to and from recording surfaces;~~ one or more head interfaces, each head interface ~~electrically connected to a transducer head~~ for controlling a~~the~~ transducer head for ~~data~~ read and~~/or~~ write operations,~~;~~ and a mode controller ~~electrically connected to the control interface and to each head interface,~~ for controlling ~~the operation of~~ each head interface based on ~~the~~ configuration information for selectively~~:~~ (i) read~~writ~~ing data from~~to~~ at least one recording surface, (ii) writ~~read~~ing data to~~from~~ at least one recording surface, and (iii) simultaneously reading data (such as a reference pattern) from at least one recording surface and writing data (such as servo patterns) to at least one recording surface. ~~The preamplifier can be used for self-servo writing a disk drive by transferring a servo reference pattern onto a recording surface of a reference disk, where the reference pattern includes servo clock information providing transducer head circumferential relative position information, and servo position information providing transducer head radial relative position information. The disk drive is assembled by installing the reference disk and one or more data disks into the disk drive and enclosing the disks and data transducers within a housing. The self-servo writing process includes the steps of reading the reference pattern from the reference disk via a head and using the read servo clock and the servo position information to precisely position and maintain one or more heads at concentric track locations of one or more disk recording surfaces while writing final servo patterns onto the recording surfaces at the concentric track locations in accordance with servo pattern features.~~